JMPM – 001

Transistor Microprocessor Kit

Assembly Instructions

Revision 1a

CONTENTS

Introduction

The JMPM-001 is a fully functional microprocessor constructed from discrete bipolar transistors. It is based on the SAP (**S**imple **A**s **P**ossible) computer concept although it has a few more advanced features such as conditional jumps and banked memory switching.
This instruction guide is intended to describe the method for assembly of the kit but does not provide schematic diagrams. Should you be interested in the schematics and design of this computer then detailed information can be found in the book 'Computer Time Travel (J. S. Walker) Oldfangled Publishing' which was written as part of the initial development of this processor.

It should be noted at this point that while the kit contains all the parts required to complete the construction of this processor it is a fairly significant task to successfully complete the build as it has a total of almost 2000 transistors and 2000 resistors along with hundreds of other components spread across 4 large circuit boards and a motherboard.

The kit has been designed in such a way that the testing of each module within each component block on each board can be easily completed by making temporary connections to the motherboard. This will be described in more detail as each part of the kit is assembled.

This kit is intended as a learning tool for anyone wanting to learn about the inner workings of microprocessors or as an interesting experiment for anyone already familiar with such devices. The design of the kit also allows for expansion and further development should the builder wish to follow up on the process.
It also provides an output port to allow interfacing to external devices or bank switching of the ROM address space providing up to 16 x 256 bytes of addressable memory locations.

JMPM Processor Specification

Architecture	Extended SAP (Proprietary)
Transistors	1740
Instructions	10
Maximum clock speed	180 KHz
On board clocks	4 Hz and 2 KHz (Selectable)
Power consumption	7W Max (1.4A @ 5V)
MIPS (max)	0.036 (36000 instructions per second)
Addressable memory	16 bytes un-banked (4k 16 x 256 bytes using banking)
Kit build time	Approximately 40 hours

Processor Layout

The 5 boards in this kit are arranged so that they contain various processor function blocks and these will be described in detail in the construction chapters for each board but they are referred to by one of the elements contained on each board in order to keep references simple.

Board 1 – Arithmetic Logic Unit (ALU)

Contains:

1) Arithmetic Logic Unit
2) ALU Tri-State bus buffer
3) Zero result detector and latch
4) Carry result detector and latch
5) Indicator LED's

Board 2 – Accumulator

Contains:

1) Accumulator Register
2) Accumulator Tri-State bus buffer
3) Register B
4) Output Register
5) Indicator LED's

Board 3 – Clock

Contains:

1) Clock Generator
2) Clock option switches
3) ROM socket and Tri-State bus buffer
4) Ring Counter
5) Program Counter and Tri-State bus buffer
6) Data Bus indicator LED's
7) Indicator LED's

Board 4 – Control Matrix

Contains:

1) Control Matrix
2) Instruction Decoder (10 instructions)
3) Instruction Register and Address Tri-State bus buffer
4) Indicator LED's

Board 5 – Motherboard

Contains:

1) 4 backplane sockets
2) Pcb Supports

The motherboard is arranged as a 100 way parallel backplane so that the 4 processor boards can be plugged into any slot although it is recommended that the Clock Module board is fitted in the front slot so that the ROM socket, mode selection switches, reset switch and single step switch can be accessed easily.

Kit Contents

Before starting assembly the contents of the kit should be checked and it should be noted that some spare components have been provided.

Note that while these instructions specify certain LED colours for each indicator you can of course substitute these for colours of your own choice but be aware that the kit does not contain equal numbers of each colour LED.

Component	Qty
Motherboard - bare pcb	1
Clock - bare pcb	1
Control Matrix - bare pcb	1
Accumulator - bare pcb	1
Arithmetic Logic Unit - bare pcb	1
Pcb Guide	8
Pcb Guide mounting screw	16
100 Way Edge connector socket	4
ZIF socket 24 way 300 mil	1
Push button switch, momentary contact	2
Push button switch cap - Red	1
Push button switch cap - Grey	1
Dil switch – 8way	1
ROM M2732A – Programmed	1
Diode BAT85	3
LED Red – 5mm	26
LED Green – 5mm	19
LED Yellow – 5mm	18
LED Blue – 5mm	27
LED Clear – 5mm	8
Capacitor 100uF 25V	9
Capacitor 1uF 50V	2
Capacitor 4n7 50v	2
Capacitor 100n 50v	43
Resistor 150R 1/6W	20
Resistor 1k 1/6W	670
Resistor 2k7 1/6W	270
Resistor 15k 1/6W	2
Resistor 100k 1/6W	500
Transistor BC547 To92	1750
Rubber Foot – Self Adhesive	5
Resistor Forming tool	1
Transistor Insertion tool	1
Instruction Manual	1
Book – Computer Time Travel (Optional)	

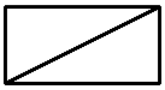
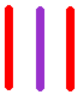
Do not start assembly until all parts have been checked, all replacement parts will only be supplied at cost.

Motherboard Backplane Connections

The connections on the motherboard are arranged as detailed in the table shown in Appendix A and the purpose of each of these connections will be explained in the appropriate sections. Some of these connections are made accessible for future expansion or experimentation.

Resistor Identification

Because this kit contains so many individual resistors but very few different values I decided when designing the boards to simplify the build process and hopefully minimise the possibility of errors by using unique pcb silk screen identifiers for the resistors.
The silk screen therefore has different symbols for each resistor value and these are shown in the table below.
When assembling the boards you simply need to insert resistors of the correct value into each location with the matching symbol. There is no need to constantly refer to the board overlay when inserting these parts.

Board Symbol		Colour Code		Value
	=		=	100k
	=		=	2k7
	=		=	150R
	=		=	1k

Check the assembly instructions for each board carefully for any exceptions.

STATIC ELECTRICITY WARNING

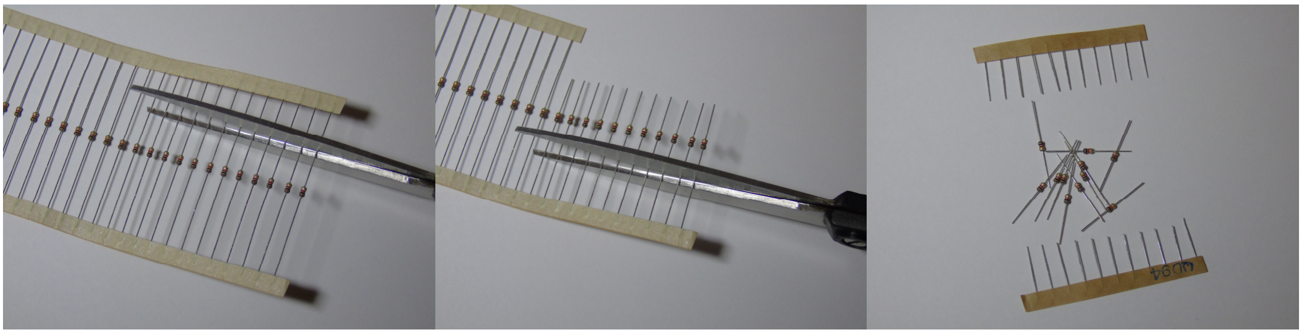
Note that some of the components used in this kit can be damaged by static electricity so normal anti static handling precautions should be taken.

Resistor Lead Forming Jig

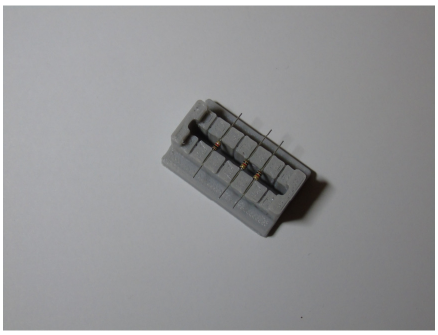
The resistors supplied in this kit are 1/8 watt so are very small and this can make it difficult to bend the leads to correctly fit them into the pcb's.
In order to make this task easier the kit is supplied with a tool for forming the resistor leads prior to fitting them into the boards.
Please review this section if you wish to use the jig (recommended).

Resistor Lead Forming Jig

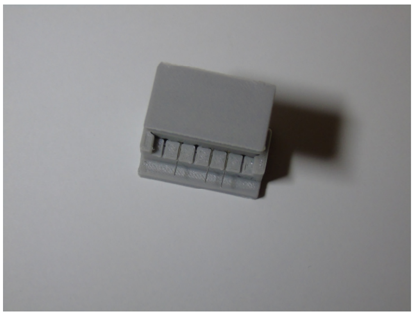
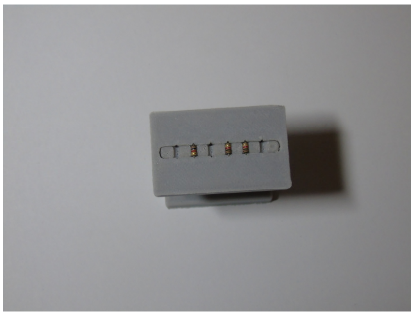
Cutting resistor leads
Step one is to cut the resistor leads to the required length which is approximately half way between the resistor tape and the resistor body as shown in the images below (Scissors save a lot of time when doing this).



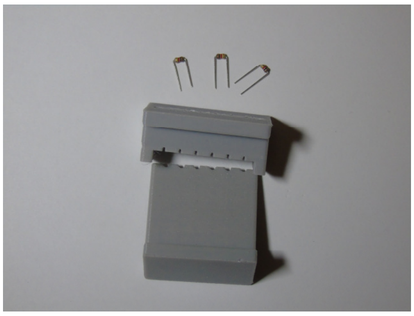
Inserting into jig
Once the resistor leads have been cut to the correct length they can be inserted into the jig as shown in the image below. More than one resistor can be formed at once as all the slots in the jig are the same.



<u>Pressing plunger all the way</u>
The jig must be on a flat surface and the plunger can then be placed into position and pushed all the way down.
The jig can be turned over and you will see that the resistor leads have been formed.

<u>Ejecting the formed resistors</u>
Finally eject the resistors from the jig by pushing the plunger as far in as it will go and then retracting it.
This will cause the resistors be ejected from the jig and they will have perfectly formed leads ready for inserting into the board.



This jig can save many hours when building the kit.

It is advised that all the resistors of a certain value are fitted together before moving on to the next value.

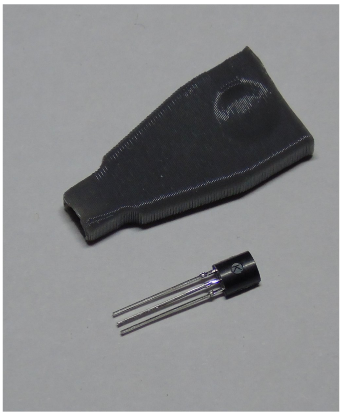
It does not matter which way round the resistors are fitted but the finished boards will look neater if they are all fitted the same way round.

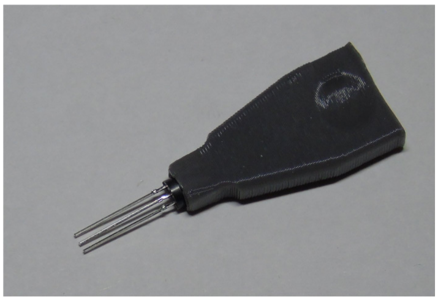
Do <u>NOT</u> use this jig to form the diode leads as this will damage the diodes.

Transistor Insertion Tool

The transistor insertion tool is very simple but allows you to insert transistors quickly and easily. To use it just follow the steps in the images below.

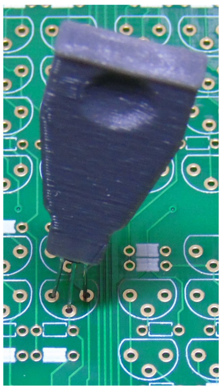
1) Fit the transistor into the jig



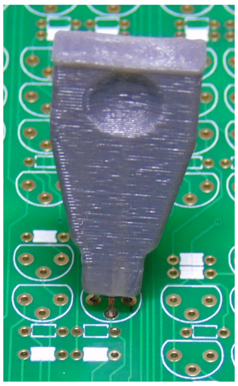


Note that the transistors will only fit one way round

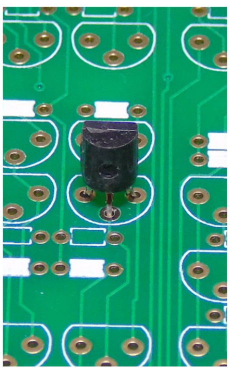
2) Insert the transistor leads into the pcb while holding it with the jig and then press down firmly while using the jig to position the transistor.
The underside of the transistor body should be approximately 2mm above the surface of the pcb.



Be sure to hold the jig perpendicular to the board when pressing it down.



3) Remove the jig leaving the transistor inserted in the pcb ready for soldering.



Assembling the motherboard

Start assembly of the kit by building the motherboard.

Step 1)
Insert the 100 way edge connectors into the bare board and turn the board over while ensuring that the connectors do not drop out or become misaligned.
It does not matter which way round the connectors are fitted.
Solder one pin at each end of each connector and then turn it over to ensure that the connectors are properly inserted and are pressed tightly up against the pcb.
Adjust if required by reheating the solder joints and once you are sure that the connectors are correctly fitted you should solder the remaining pins.

> IMPORTANT
> There are a large number of solder joints to be made during construction of this kit so it is strongly advised to examine each block of joints as it is completed to make sure that there are no dry joints or missed joints or solder bridges.

Step 2)
Using the self tapping screws you should fit the pcb guides to the motherboard. There is some adjustment possible so you can use one of the bare pcb's to check that the guides are properly aligned before tightening the screws.

DO NOT OVER TIGHTEN THE SCREWS.

Step 3)
Fit a self adhesive rubber foot to each corner on the solder side of the board and one in the centre of the board.
The motherboard assembly will then sit level on the bench.

Step 4)
Connect suitably identifiable power cables to the 0V and +5V motherboard connectors (Cable Not supplied).

Be absolutely sure to connect these the correct way round as improper connection can seriously damage thousands of components.

> TIP
> Fit a power diode in line with your power cable to prevent accidental reverse polarity (It should be able to handle at least 2A).

> TIP
> Turned pins taken from an IC socket can be fitted to the motherboard terminations to enable easy connection of flexible jumpers.

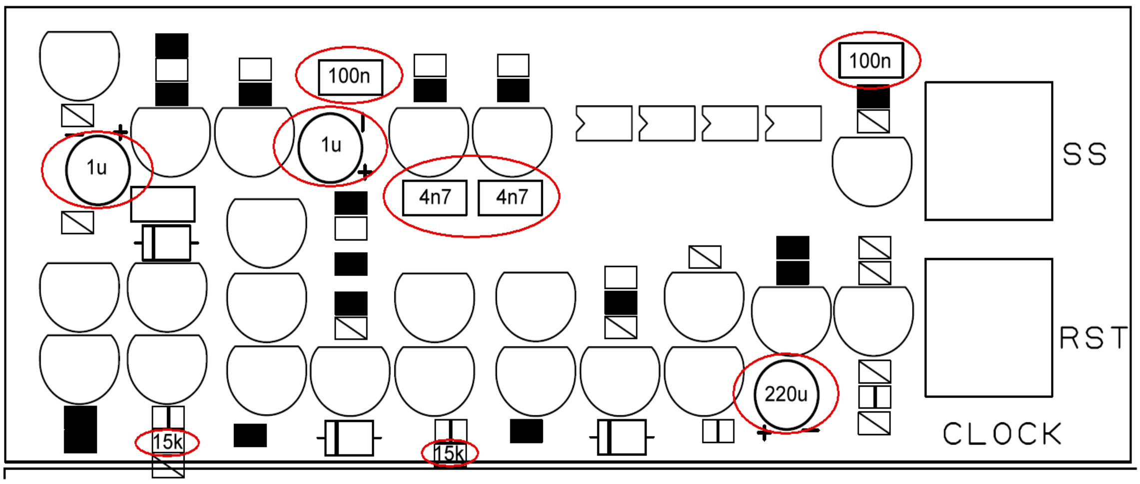
Assembling the Clock board

It is best to start assembly of the circuit boards with the Clock Module as this is needed for testing the other boards.

Step 1)
Fit all the resistors to the board ensuring that they are in the correct locations.
It is advisable to prepare and fit all the resistors of each value in turn to avoid any errors.

Step 2)
Fit all the capacitors. Be sure to fit the electrolytic capacitors the right way round.
See the diagram below which shows where each value of capacitor should be fitted in the clock generator area of the board.

All resistors in the clock area shown below should be the values indicated by the standard board placement symbols except those indicated which should be the values shown.
All other areas of the clock board should follow the normal resistor identification.



Step 3)
Fit all the transistors. They should be fitted by inserting all three leads through the pcb while ensuring that the transistor body shape matches the silk screen outline and then pushing the transistor down into the board until there is approximately 2mm between the underside of the transistor body and the pcb. This will form the leads into the correct shape.
Avoid using excessive force as this may damage the pcb or the transistor.
A special tool is included in the kit for this purpose and will save a lot of time.

Step 4)
Fit all the LED's as indicated below being sure to fit them the correct way round (They have a flat adjacent one of the pins and this should be fitted as indicated on the board silk screen).

DATA BUS	Yellow
PROGRAM CNT	Red
CLOCK	Green
CLEAR	Yellow
PHASE	Blue
OPCODE	Red
ARGUMENT	Yellow
ADDRESS	Green

Step 5)
Fit the 8 way DIL switch.

Step 6)
Fit the two push buttons.

Step 7)
Fit the ROM socket (Do Not fit the ROM yet).

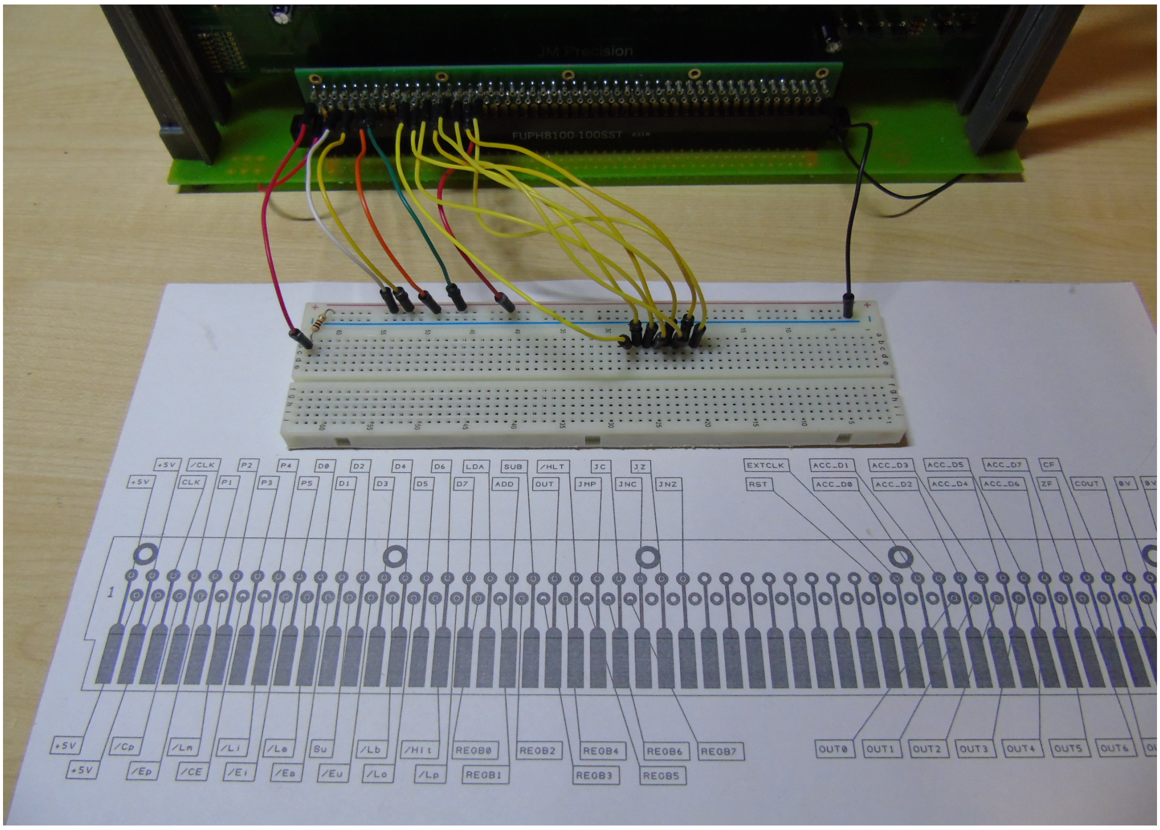
General Notes on testing the boards.

This applies to all board testing.
In general each board should initially be tested on its own with all other boards removed (except the test adaptor board if you have purchased one of those).
Testing involves applying power to the board and setting various states on the control and data lines and this is most easily accomplished by using flexible jumper wires either soldered directly to the motherboard edge connections or better still by using our interface adaptor board (or turned pins fitted to the motherboard).
Appendix H shows the connections for both of these options and this diagram should be used to determine where to connect the various jumpers.
Pay particular attention to the 0V and +5V connections as getting these wrong can destroy thousands of components.

IMPORTANT !

When making test connections to the boards it is very important that you do NOT connect any of the data bus lines directly to the +5V rail as this will cause damage.
To set the Data Bus values connect the appropriate jumper wires to 0V for a logic 0 and leave them **floating (unconnected)** for a logic 1.
Control lines should be connected to either +5V or 0V as indicated in the test steps.

Using a small breadboard to make the jumper wire connections makes testing easier and is less likely to result in damage.
The image below shows the Clock Module board set up for testing. As you can see the data bus lines are all plugged into unconnected points on the breadboard and so are effectively floating.
Remember, NEVER connect them directly to +5V as this will cause damage.
To avoid making mistakes include a 150R resistor between the +5V rail and the +Ve bus on the breadboard.



All of the boards contain several processor modules and they are tested in turn.
Should you encounter any problems then carefully check all connections and that all components are correctly fitted in the right locations.

TIP

Much of the testing requires the latching of data values into various registers and this involves moving the appropriate jumper from the +5V rail to 0V and then back to the +5V rail.
To avoid a lot of tedious repetition in the instructions I will simply use the term ‘Strobe’ to indicate this operation.

Example
‘Strobe /Lp’ means move the jumper connected to the /Lp line from +5V to 0V and then back to the +5V line.

Testing the Clock Module Board

Attach jumpers to the following lines by either connecting them using the adaptor board or by soldering them directly to the connections along the front of the motherboard (or using turned pin connectors soldered to the motherboard).

/Cp	/Ep	/Lm	/CE	/Lp
Connect all of these lines to +5V				

D0	D1	D2	D3	D4	D5	D6	D7
Leave all these inputs floating (Logic 1).							

Set all the DIP switches to off except switch 3 which should be set to on.
Ensure that the ROM chip is Not fitted.

Carefully check all connections and then apply 5V power to the motherboard (I Strongly recommend using a current limited power supply set to a current limit 0f 450mA).

If a current much more than 450mA is drawn then immediately power off and check all connections and components for errors.

Assuming all is well so far then you should see the following LED indications.

ADDRESS	All off
ARGUMENT	All off
OPCODE	All off
PHASE	Flashing alternatively from right to left
CLEAR	Off (On briefly when power is first applied).
CLOCK	Alternately flashing
PROGRAM CNT	All off
DATA BUS	All on

Investigate any errors (start by pressing the reset button for approximately 1 second).

Assuming all indications are correct then testing can begin so proceed as follows.

Testing the Ring Counter

Test 1	Press the reset button and ensure that the counter resets each time so that just the right most LED is illuminated. It should start counting again as soon as the reset button is released.	

Testing the Data Bus Indicators

Test 1	Connect each Data Bus jumper (D0 – D7) to 0V in turn and check that the corresponding LED turns off.	
Test 2	Move each Data Bus jumper (D0 – D7) to their floating positions and check that each LED turns on.	

Testing the Address Latch

Test 1	Strobe /Lm and check that the ADDRESS LED's show the same value as the Data Bus D0 – D3 LEDs.	
Test 2	Repeat test 1 after setting different values on the D0-D3 Data Bus jumpers. Each time that /Lm is strobed the value on the D0-D3 inputs should be latched and the latched value displayed on the ADDRESS LED's.	

Testing the Program Counter

If you have read the book relating to this processor design then the program counter is one of the major deviations from the original design.
Because this version of the processor supports programmatic jumps (JMP, JC, JNC, JZ and JNZ) then the program counter needs to not only be re-settable but also loadable. The circuit in this processor is therefore much more complex than the original version and there are a few extra test steps.

Test 1	Move all the Data Bus jumpers to their floating positions so that all the Data Bus LED's are illuminated.	
Test 2	Press the reset button and check that the PROGRAM CNT LED's are all off.	
Test 3	Move the /Cp jumper to 0V and check that the PROGRAM CNT LED's show the counter value is counting.	
Test 4	Move the /Cp jumper to +5V and check that the Program counter stops counting but retains the current count value.	
Test 5	Press the reset button and check that the PROGRAM CNT LED's are all off.	
Test 6	Repeat test steps 3 to 5 a number of times and check that the counter works correctly each time.	
Test 7	Ensure that the /Cp jumper is connected to +5V and that the program counter is stopped and then set the D0-D3 jumpers to give an input value of 1010 (as indicated on the Data Bus LED's).	
Test 8	Strobe the /Lp input and check that the Program counter now contains the value 1010.	
Test 9	Move the D0-D3 jumpers back to their floating positions.	
Test 10	Move the /Ep jumper to 0V and check that the D0-D3 Data Bus LED's show a value of 1010.	
Test 11	Move the /Ep jumper to +5V and check that the D0-D3 Data Bus LED's show a value of 1111.	
Test 12	Repeat test steps 7 to 11 a number of times using different Data Bus input values and check that the correct value is latched into the Program Counter each time.	

Testing the ROM

Power off the board and fit the supplied ROM into the board ROM socket.
Apply power to the board and check that the current drawn is not significantly greater than 450mA.

Test 1	Set each D0-D3 jumper to 0V and ensure that the Data Bus LED's show a value of 00001111.	
Test 2	Strobe the /Lm jumper and ensure that the value set on D0-D3 is indicated on the ADDRESS LED's.	
Test 3	Refer to the table below and ensure that the correct ARGUMENT and OPCODE values are shown on the corresponding LED's. Test 4) Move the D0-D3 jumpers to their floating positions and check that all the Data Bus LED's are illuminated.	
Test 4	Move the D0-D3 jumpers to their floating positions and check that all the Data Bus LED's are illuminated.	
Test 5	Move the /CE jumper to 0V and check that the D0-D3 Data Bus LED's show the ADDRESS value and that the D4-D7 LED's show the OPCODE value.	
Test 6	Move the /CE jumper to +5V and check that the D0-D7 Data Bus LED's show a value of 11111111.	
Test 7	Repeat test steps 1 to 6 for each Address value in the table below and check that the corresponding ARGUMENT and OPCODE values are shown on the LED's and are correctly indicated on the Data Bus LED's in test step 5.	

ROM Data Values Test Table

ADDRESS	OPCODE	ARGUMENT
0000	0000	1111
0001	1110	0000
0010	0010	1110
0011	1100	0001
0100	1111	0000
0101	1111	1111
0110	1111	1111
0111	1111	1111
1000	1111	1111
1001	1111	1111
1010	1111	1111
1011	1111	1111
1100	1111	1111
1101	1111	1111
1110	0000	0001
1111	1111	1111

Initial testing of the Clock Module board is now complete so remove power off the board and remove it from the motherboard so that the next board can be fitted.

Any faults found should be corrected before proceeding.

Assembling the Control Matrix board

Step 1)
Fit all the resistors to the board ensuring that they are in the correct locations.
It is advisable to prepare and fit all the resistors of each value in turn to avoid any errors.

Step 2)
Fit all the capacitors.

Step 3)
They should be fitted by inserting all three leads through the pcb while ensuring that the transistor body shape matches the silk screen outline and then pushing the transistor down into the board until there is approximately 2mm between the underside of the transistor body and the pcb. This will form the leads into the correct shape.
Avoid using excessive force as this may damage the pcb or the transistor.

Step 4)
Fit all the LED's as indicated below being sure to fit them the correct way round (They have a flat adjacent one of the pins and this should be fitted as indicated on the board silk screen).

Control Lines	Blue
Instructions	Red
ARGUMENT	Yellow
OPCODE	Green

Testing the Control Matrix board

Attach jumpers to the following lines by either connecting them using the adaptor board or by soldering them directly to the connections along the front of the motherboard.

/Clk	/Clr	/Ei	/Li
Connect all of these lines to +5V			

ZF	CF
Connect these two lines to 0V	

D0	D1	D2	D3	D4	D5	D6	D7
Leave all these inputs floating (Logic 1).							

P1	P2	P3	P4	P5
Connect P1 to +5V and P2 to P5 to 0V				

Set all the DIP switches to off except switch 3 which should be set to on.
Ensure that the ROM chip is Not fitted.

Carefully check all connections and then apply 5V power to the motherboard (It is strongly recommend that a current limited power supply is used and it should be set to a current limit 0f 450mA to test this board).

If a current much more than 450mA is drawn then immediately power off and check all connections and components for errors.

Ignore the LED indications at this point.

Investigate any errors (start by pressing the reset button for approximately 1 second).
Assuming all indications are correct then testing can begin so proceed as follows.

Testing the Instruction Register

Test 1	Set the D0 to D7 jumpers to give an input of 11110000.	
Test 2	Strobe /Li and check that the OPCODE and ARGUMENT LED's show 1111 and 0000 respectively.	
Test 3	Move the D0 to D7 jumpers back to their floating positions.	
Test 4	Move /Ei to 0V and use a multi-meter and check that D0 to D3 have values of 0000.	
Test 5	Move /Ei to +5V and check that D0 to D3 have values of 1111.	
Test 6	Repeat test steps 1 to 5 for several different combinations of Data Values and ensure that the register correctly latches and outputs the values.	

Testing the Instruction Decoder

Test 1	Referring to the table below set the first entry value in the OPCODE column on data lines D4 to D7 where 0 = 0V and 1 = Floating (NOT +5V).	
Test 2	Strobe /Li and check that the correct value is shown on the OPCODE LED's and that only the LED corresponding to the LED Illuminated column in the table is ON.	
Test 3	Repeat test steps 1 and 2 for all the values in the table.	

OPCODE Value	LED Illuminated
0000	LDA
0001	ADD
0010	SUB
1110	OUT
1111	HLT
1100	JMP
1011	JC
0100	JNC
1010	JZ
0101	JNZ

Testing the Control Matrix

Test 1	Referring to the OPCODE table in the previous test module set the first entry value in the OPCODE column on data lines D4 to D7 where 0 = 0V and 1 = Floating (NOT +5V).	
Test 2	Strobe /Li and check that the correct value is shown on the OPCODE LED's and that only the LED corresponding to the LED Illuminated column in the table is ON.	
Test 3	With the P1 to P5 inputs set to 10000 (only P1 high) check that the /Ep and /Lm LED's are ON.	
Test 4	With the P1 to P5 inputs set to 01000 (only P2 high) check that the /Cp, /CE and /Li LED's are on.	
Test 5	Continue setting each phase in turn using the P1 to P5 inputs and check at each phase that the correct LED's are on as indicated in the table below.	
Test 6	Repeat test steps 1 to 5 for all the instructions in the table below.	

Note: For the JZ test the Z flag input should be high and low for the JNZ Test.
For the JC test the C flag input should be high and low for the JNC Test.

Control Matrix Test Table

Op-code	Phase	/Cp	/Ep	/Lm	/CE	/Li	/Ei	/La	/Ea	Su	/Eu	/Lb	/Lo	/Lp	/Hlt
LDA	1		ON	ON											
LDA	2	ON			ON	ON									
LDA	3			ON			ON								
LDA	4				ON			ON							
LDA	5														
Add	1		ON	ON											
Add	2	ON			ON	ON									
Add	3			ON			ON								
Add	4				ON							ON			
Add	5							ON			ON				
Sub	1		ON	ON											
Sub	2	ON			ON	ON									
Sub	3			ON			ON					ON			
Sub	4				ON							ON			
Sub	5							ON		ON	ON				
Out	1		ON	ON											
Out	2	ON			ON	ON									
Out	3								ON				ON		
Out	4														
Out	5														
halt	1		ON	ON											
halt	2	ON			ON	ON									
halt	3														ON
halt	4														
halt	5														
JMP	1		ON	ON											
JMP	2	ON			ON	ON									

JMP	3						ON							ON	
JMP	4														
JMP	5														
JZ	1		ON	ON											
JZ	2	ON			ON	ON									
JZ	3						ON							ON	
JZ	4														
JZ	5														
JNZ	1		ON	ON											
JNZ	2	ON			ON	ON									
JNZ	3						ON							ON	
JNZ	4														
JNZ	5														
JC	1		ON	ON											
JC	2	ON			ON	ON									
JC	3						ON							ON	
JC	4														
JC	5														
JNC	1		ON	ON											
JNC	2	ON			ON	ON									
JNC	3						ON							ON	
JNC	4														
JNC	5														

Initial testing of the Control Matrix Module board is now complete so turn off power to the board and remove it from the motherboard so that the next board can be fitted.

Any faults found should be corrected before proceeding.

Assembling the ALU board

See Appendix D for an image of this board.

Step 1)
Fit all the resistors to the board ensuring that they are in the correct locations.
It is advisable to prepare and fit all the resistors of each value in turn to avoid any errors.

Step 2)
Fit all the capacitors.

Step 3)
They should be fitted by inserting all three leads through the pcb while ensuring that the transistor body shape matches the silk screen outline and then pushing the transistor down into the board until there is approximately 2mm between the underside of the transistor body and the pcb. This will form the leads into the correct shape.
Avoid using excessive force as this may damage the pcb or the transistor.

Step 4)
Fit all the LED's as indicated below being sure to fit them the correct way round (They have a flat adjacent one of the pins and this should be fitted as indicated on the board silk screen).

ALU REGISTER	Blue
C	Yellow
Z	Green

Testing the ALU

To test the ALU you should connect temporary flexible jumper wires to the REGB0 – REGB7 input lines and the ACC_D0 - ACC_D7 input lines on the motherboard (Refer to Appendix A for information on the data bus connections).
It is easiest to carry out these tests if the flexible jumper wires are plugged into a small breadboard).

IMPORTANT
Always make connections using 1k resistors in series with the flexible jumper wires to avoid damaging any components.

You can then use these flexible jumpers to set specific input values on both the A and B register inputs to the ALU.
Also connect jumpers to the /Eu, Su, 0v and +5V lines.
Note that the ALU operation is asynchronous and so it does not have a clock connection. As soon as values are applied to the inputs then the LED's will shown the results of the calculation.
Only the ALU board should be plugged in while carrying out these tests.

Begin by setting all the data lines and Su to 0V and /Eu to +5V.

All the ALU Register LED's should be off. The Carry LED should be off and the Zero LED should be on.

Now set two binary values on the two data inputs by connecting the jumpers on the data lines to 0V or +5V to give the required number (+5V represents a one and 0V represents a zero).

Once you have the input values set apply power and you should immediately see the correct result on the ALU Register LED's.
For example if you set the A and B inputs at 10000000b (128 decimal) and 00000001b (1 decimal) respectively then the LED's should show a value of 10000001b (129).
If you now move the Su jumper to +5v to set the ALU into subtraction mode then the value shown by the LED's should immediately change to 01111111b (127).
You should test a few different combinations and make sure that each gives the right answer.
Two good values to try are 10101010b and 01010101b which should give a result of 11111111b when you put one number into A and the other into B and then try the same the other way round. This will test that all the bits are in the right order which is the most likely wiring error.
Once you are happy that the ALU is calculating the correct values then you should test that the output buffer is working by checking that the current value shown by the LED's appears on the buffer output when the /Eu line is connected to 0V and that the output goes into a high impedance state when the /Eu line is connected to +5V.

Note that the Carry and Zero flag outputs to the motherboard will not be updated as the data values change as there is no clock to update the latches.

If the board is not working as expected then check that all components have been correctly fitted and that you have made the correct input connections.
It is advisable to get the board working correctly before moving onto the next assembly step.

Assembling the Accumulator board

Step 1)
Fit all the resistors to the board ensuring that they are in the correct locations.
It is advisable to prepare and fit all the resistors of each value in turn to avoid any errors.

Step 2)
Fit all the capacitors.

Step 3)
They should be fitted by inserting all three leads through the pcb while ensuring that the transistor body shape matches the silk screen outline and then pushing the transistor down into the board until there is approximately 2mm between the underside of the transistor body and the pcb. This will form the leads into the correct shape.
Avoid using excessive force as this may damage the pcb or the transistor.

Step 4)
Fit all the LED's as indicated below being sure to fit them the correct way round (They have a flat adjacent one of the pins and this should be fitted as indicated on the board silk screen).

OUTPUT REGISTER	White
REGISTER B	Green
ACCUMULATOR REGISTER	Red

Testing the Accumulator Register

Attach jumpers to the following lines by either connecting them using the adaptor board or by soldering them directly to the connections along the front of the motherboard.

/CLK /CLR /La /Ea
Connect all of these lines to +5V

D0	D1	D2	D3	D4	D5	D6	D7
Connect all the data lines to 0V (Logic 0)							

Test 1	Power up the board. Note that a random data value may be indicated on the LED's.	
Test 2	Strobe /CLR and check that all the LED's turn off.	
Test 3	Set a data bus value of 10101010 (Remember that a 1 is set by leaving the input floating and NOT connecting to +5V).	
Test 4	Connect /La to 0V	
Test 5	Strobe /CLK and check that all the LED's show a value of 10101010.	
Test 6	Return /La to +5V and check that the LED's still show a value of 10101010.	
Test 7	Repeat test steps 1 to 6 for several different combinations of Data Values and ensure that the register correctly latches and displays the values.	

Power off the board when you have finished testing.

Testing Register B

Attach jumpers to the following lines by either connecting them using the adaptor board or by soldering them directly to the connections along the front of the motherboard.

/CLK /CLR /Lb /Ea
Connect all of these lines to +5V

D0	D1	D2	D3	D4	D5	D6	D7
Connect all the data lines to 0V (Logic 0).							

Test 1	Power up the board. Note that a random data value may be indicated on the LED's.	
Test 2	Strobe /CLR and check that all the LED's turn off.	
Test 3	Set a data bus value of 10101010 (Remember that a 1 is set by leaving the input floating and NOT connecting to +5V).	
Test 4	Connect /Lb to 0V	
Test 5	Strobe /CLK and check that all the LED's show a value of 10101010.	
Test 6	Return /Lb to +5V and check that the LED's still show a value of 10101010.	
Test 7	Repeat test steps 1 to 6 for several different combinations of Data Values and ensure that the register correctly latches and displays the values.	

Power off the board when you have finished testing.

Testing the Output Register

Attach jumpers to the following lines by either connecting them using the adaptor board or by soldering them directly to the connections along the front of the motherboard.

/CLK /CLR /Lo /Ea
Connect all of these lines to +5V

D0	D1	D2	D3	D4	D5	D6	D7
Connect all the data lines to 0V (Logic 0)							

Test 1	Power up the board. Note that a random data value may be indicated on the LED's.	
Test 2	Strobe /CLR and check that all the LED's turn off.	
Test 3	Set a data bus value of 10101010 (Remember that a 1 is set by leaving the input floating and NOT connecting to +5V).	
Test 4	Connect /Lo to 0V	
Test 5	Strobe /CLK and check that all the LED's show a value of 10101010.	
Test 6	Return /Lo to +5V and check that the LED's still show a value of 10101010.	
Test 7	Repeat test steps 1 to 6 for several different combinations of Data Values and ensure that the register correctly latches and displays the values.	

Power off the board when you have finished testing.

Testing the Completed Processor

Once all the boards have been successfully tested then the finished processor can be tested as a complete unit.
The ROM should be programmed with a test program and fitted into the socket.
Power can then be applied.
Be sure to power off the processor before fitting or removing the ROM otherwise it may be permanently damaged.

The completed processor should draw approximately 1.3A at 5V.
You can test the various functions by selecting the appropriate DIL switch as indicated in the table below.

Switch	Function
1	Selects single step clock mode and allows you to step the processor by single clock cycles and also allows you to hold the clock line either high or low to check that the clocked circuits are responding properly to the clock states and edges. SW3 and SW5 must be in the OFF positions to use this function.
2	Not Used
3	Selects slow clock mode where the processor is clocked at a frequency of 4 Hz with a duty cycle of 50%. This mode is useful for examining the way in which the processor is working on a clock by clock basis. SW1 and SW5 must be in the OFF positions to use this function.
4	Not Used
5	Selects fast clock mode where the processor is clocked at a frequency of 2 KHz. In this mode the switching of most signals will not be observable as they are running too quickly but this mode is useful for examining the way that programs are executing and the way that output data is changing in response to the program code. SW1 and SW3 must be in the OFF positions to use this function.
6	When this switch is set to ON the processor will be halted when a /HLT instruction is executed and will remain stopped until it is restarted by either pressing the reset button or cycling the power. If this switch is set to OFF then the processor will ignore /HLT instructions and continue to fetch and execute the instruction following the /HLT instruction. SW8 must be in the OFF position to use this function.
7	Selects the external clock mode. In this mode an external clock signal of 0-5V can be applied so that the clock frequency can be set as required. Input impedance is approximately 1k. SW1, SW3 and SW5 must be in the OFF positions to use this function.
8	When this switch is set to ON the processor will be reset when a /HLT instruction is executed which will cause all registers to be reset and the program to begin execution from the start address of 0000b. This option overrides the SW7 program halt mode.

Further Information

Please note that it is beyond the scope of this assembly guide to provide detailed information of every aspect of the processor design. Anyone wanting to know more about this should obtain a copy of the book ‘Computer Time Travel’ published by ‘Oldfangled Publishing’ which provides a lot of detailed information.

Once completed the processor can be used as the basis for further experimentation and as with any processor it can be programmed to perform different functions.

The resistors at the bottom left corner of the Clock board can be used to select banked memory operation if required.

Many of the processor signals have been made available at the backplane (See Appendix A) which allows closer examination of the processor operation as well as expansion of the processor to provide additional features.
It would be perfectly possible to add extra circuits to give things such as a working register and additional input and output ports.
It is left up to the builder to design and add these circuits although JM Precision may release add on boards at some time in the future.

Appendix A – Motherboard Backplane Connections

Side	Pin	0-100	Description	Abbr
Top	1	1	+5V	+5V
Top	2	2	+5V	+5V
Top	3	3	CLK - System Clock - Phase 1	CLK
Top	4	4	CLK_ - System Clock - Phase 2	CLK_
Top	5	5	Instruction Phase 1	P1
Top	6	6	Instruction Phase 2	P2
Top	7	7	Instruction Phase 3	P3
Top	8	8	Instruction Phase 4	P4
Top	9	9	Instruction Phase 5	P5
Top	10	10	Data Bus Bit 0	D0
Top	11	11	Data Bus Bit 1	D1
Top	12	12	Data Bus Bit 2	D2
Top	13	13	Data Bus Bit 3	D3
Top	14	14	Data Bus Bit 4	D4
Top	15	15	Data Bus Bit 5	D5
Top	16	16	Data Bus Bit 6	D6
Top	17	17	Data Bus Bit 7	D7
Top	18	18	Load register A from memory	LDA
Top	19	19	Add value at operand address to A	ADD
Top	20	20	Subtract value at operand address from A	SUB
Top	21	21	Output ALU value to the Output register	OUT
Top	22	22	Halt the processor	/HLT
Top	23	23	Jump	JMP
Top	24	24	Jump if Carry	JC
Top	25	25	Jump if No Carry	JNC
Top	26	26	Jump if Zero	JZ
Top	27	27	Jump if Not Zero	JNZ
Top	28	28		
Top	29	29		
Top	30	30		
Top	31	31		
Top	32	32		
Top	33	33		
Top	34	34		
Top	35	35		
Top	36	36	Reset	RST
Top	37	37	External Clock	EXTCLK
Top	38	38	Accumulator Data Out Bit 0	ACC_D0
Top	39	39	Accumulator Data Out Bit 1	ACC_D1
Top	40	40	Accumulator Data Out Bit 2	ACC_D2
Top	41	41	Accumulator Data Out Bit 3	ACC_D3
Top	42	42	Accumulator Data Out Bit 4	ACC_D4
Top	43	43	Accumulator Data Out Bit 5	ACC_D5
Top	44	44	Accumulator Data Out Bit 6	ACC_D6
Top	45	45	Accumulator Data Out Bit 7	ACC_D7
Top	46	46	Zero Flag	ZF
Top	47	47	Carry Flag	CF
Top	48	48	Cary Out From ALU	COUT

Top	49	49	0V	0V
Top	50	50	0V	0V
Bottom	1	51	+5V	+5V
Bottom	2	52	+5V	+5V
Bottom	3	53	Causes the Program Counter to be incremented by the clock.	/Cp
Bottom	4	54	Allows the Program Counter to be connected to the data bus	/Ep
Bottom	5	55	Latches the data bus contents into the memory address decoder	/Lm
Bottom	6	56	Allows the Memory to be connected to the data bus	/CE
Bottom	7	57	Latches the data bus instruction bits into the instruction register	/Li
Bottom	8	58	Latches the instruction address bits onto the data bus	/Ei
Bottom	9	59	Latches the data bus contents into register A (Accumulator)	/La
Bottom	10	60	Allows ACCU register output to be connected to the data bus	/Ea
Bottom	11	61	Controls the ALU add or subtract function	Su
Bottom	12	62	Allows the ALU output to be connected to the data bus	/Eu
Bottom	13	63	Latches the data bus contents into register B	/Lb
Bottom	14	64	Latches the data bus contents into the output register	/Lo
Bottom	15	65	Stops the main clock and halts the processor	/Hlt
Bottom	16	66	Causes the program counter to latch in the current address value	/Lp
Bottom	17	67	Register B Data Out Bit 0	REGB0
Bottom	18	68	Register B Data Out Bit 1	REGB1
Bottom	19	69	Register B Data Out Bit 2	REGB2
Bottom	20	70	Register B Data Out Bit 3	REGB3
Bottom	21	71	Register B Data Out Bit 4	REGB4
Bottom	22	72	Register B Data Out Bit 5	REGB5
Bottom	23	73	Register B Data Out Bit 6	REGB6
Bottom	24	74	Register B Data Out Bit 7	REGB7
Bottom	25	75		
Bottom	26	76		
Bottom	27	77		
Bottom	28	78		
Bottom	29	79		
Bottom	30	80		
Bottom	31	81		
Bottom	32	82		
Bottom	33	83		
Bottom	34	84		
Bottom	35	85		
Bottom	36	86		
Bottom	37	87		
Bottom	38	88		
Bottom	39	89	Output Register Bit 0	OUT0
Bottom	40	90	Output Register Bit 1	OUT1
Bottom	41	91	Output Register Bit 2	OUT2
Bottom	42	92	Output Register Bit 3	OUT3
Bottom	43	93	Output Register Bit 4	OUT4
Bottom	44	94	Output Register Bit 5	OUT5
Bottom	45	95	Output Register Bit 6	OUT6
Bottom	46	96	Output Register Bit 7	OUT7
Bottom	47	97	Master Clear active high	CLR
Bottom	48	98	Master Clear active low	/CLR
Bottom	49	99	0V	0V
Bottom	50	100	0V	0V

Appendix B - Instruction Set

The following table shows the instructions supported by the processor.

Description	Mnemonic	OP Code
Load register A from memory	LDA	0000aaaa
Add value at operand address to A	ADD	0001aaaa
Subtract value at operand address from A	SUB	0010aaaa
Output ALU value to the Output register	OUT	1110xxxx
Halt the processor	/HLT	1111xxxx
Jump	JMP	1100aaaa
Jump if Carry	JC	1011aaaa
Jump if No Carry	JNC	0100aaaa
Jump if Zero	JZ	1010aaaa
Jump if Not Zero	JNZ	0101aaaa

Appendix C – Test Programs

Test Program 1 – Counting up in the output register

Address	Data Value	HEX	Instruction
0000	0000 1111	0F	Load register A with data value at address 1111
0001	0001 1110	1E	Add the value at address 1110 to register A
0010	1110 0000	E0	Copy the data value in A to the output register
0011	1100 0001	C1	Jump to address 0001
0100	1110 0000	F0	Halt the processor
0101	1111 0000	F0	Halt the processor
0110	1111 0000	F0	Halt the processor
0111	1111 0000	F0	Halt the processor
1000	1111 0000	F0	Halt the processor
1001	1111 0000	F0	Halt the processor
1010	1111 0000	F0	Halt the processor
1011	1111 0000	F0	Halt the processor
1100	1111 0000	F0	Halt the processor
1101	1111 0000	F0	Halt the processor
1110	00000001	01	Data value 2
1111	00000000	00	Data value 1

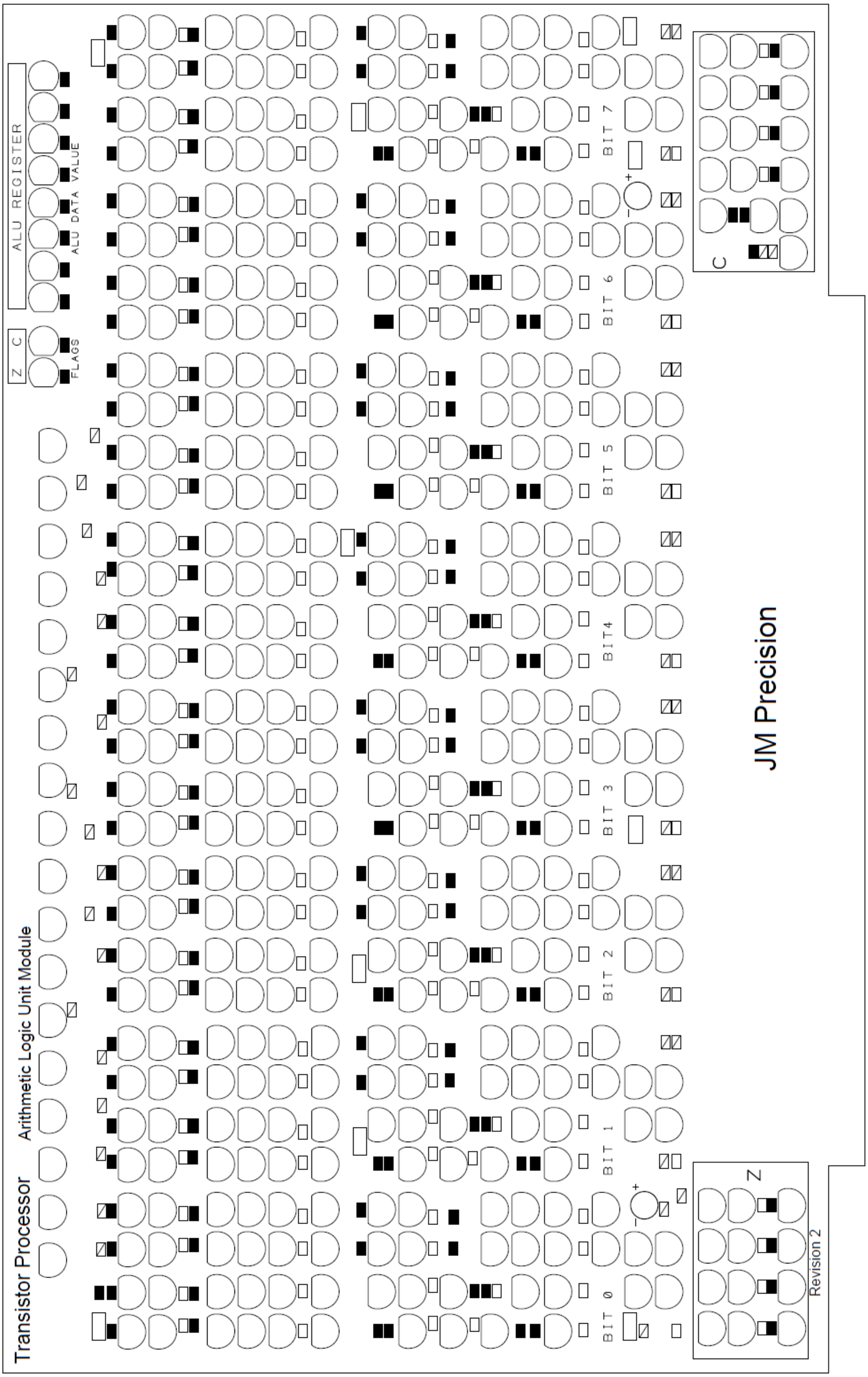
Test Program 2 – Counting down in the output register

Address	Data Value	HEX	Instruction
0000	0000 1111	0F	Load register A with data value at address 1111
0001	1110 0000	E0	Copy the data value in A to the output register
0010	0010 1110	2E	Subtract the value at address 1110 from A
0011	1100 0001	C1	Jump to address 0001
0100	1110 0000	F0	Halt the processor
0101	1111 0000	F0	Halt the processor
0110	1111 0000	F0	Halt the processor
0111	1111 0000	F0	Halt the processor
1000	1111 0000	F0	Halt the processor
1001	1111 0000	F0	Halt the processor
1010	1111 0000	F0	Halt the processor
1011	1111 0000	F0	Halt the processor
1100	1111 0000	F0	Halt the processor
1101	1111 0000	F0	Halt the processor
1110	00000001	01	Data value 2
1111	11111111	FF	Data value 1

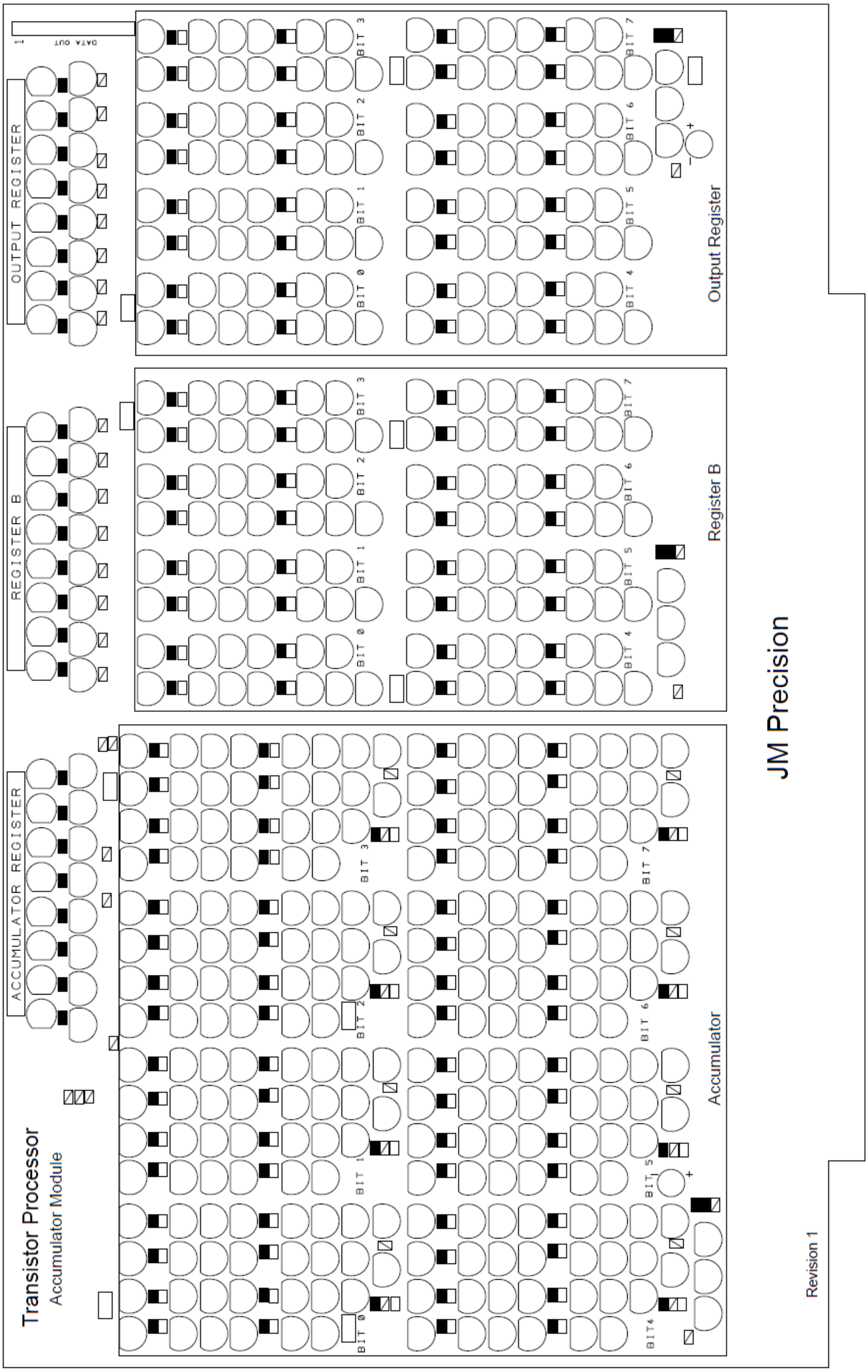
Test Program 3 – Jump Zero Test

Address	Data Value	HEX	Instruction
0000	0000 1111	0F	Load register A with data value at address 1111
0001	0101 1100	5C	Jump if Not Zero to address 1100
0010	0000 1110	0E	Load register A with data value at address 1110
0011	1010 1100	AC	Jump if Zero to address 1100
0100	0000 1110	0E	Load register A with data value at address 1110
0101	0101 1100	5C	Jump if Not Zero to address 1100
0110	1111 0000	C0	Jump to address 0000
0111	1111 0000	F0	Halt the processor
1000	1111 0000	F0	Halt the processor
1001	1111 0000	F0	Halt the processor
1010	1111 0000	F0	Halt the processor
1011	1111 0000	F0	Halt the processor
1100	1111 0000	F0	Halt the processor (Jump destination)
1101	1111 0000	F0	Halt the processor
1110	00000001	01	Data value 2
1111	00000000	00	Data value 1

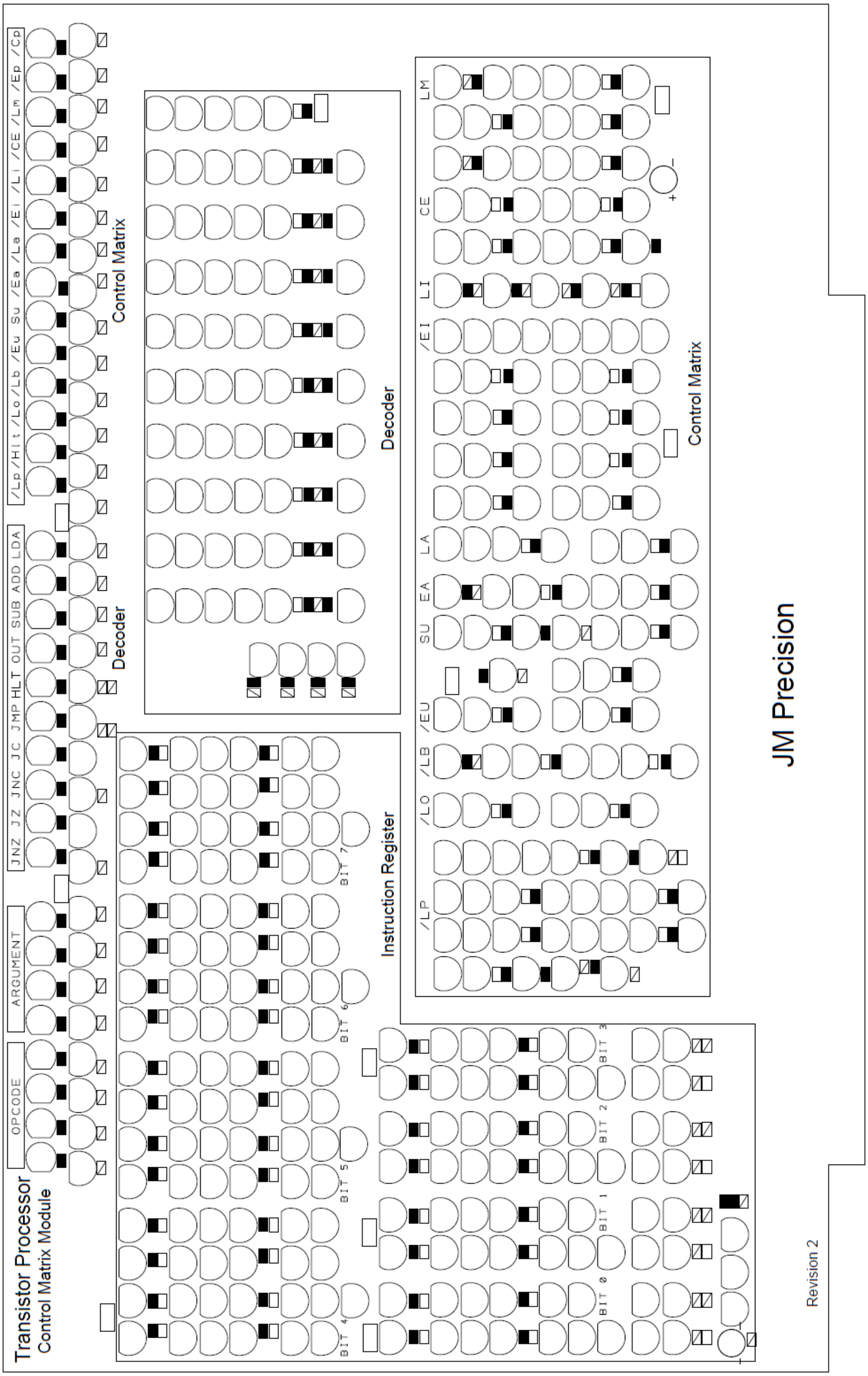
Appendix D – ALU Board



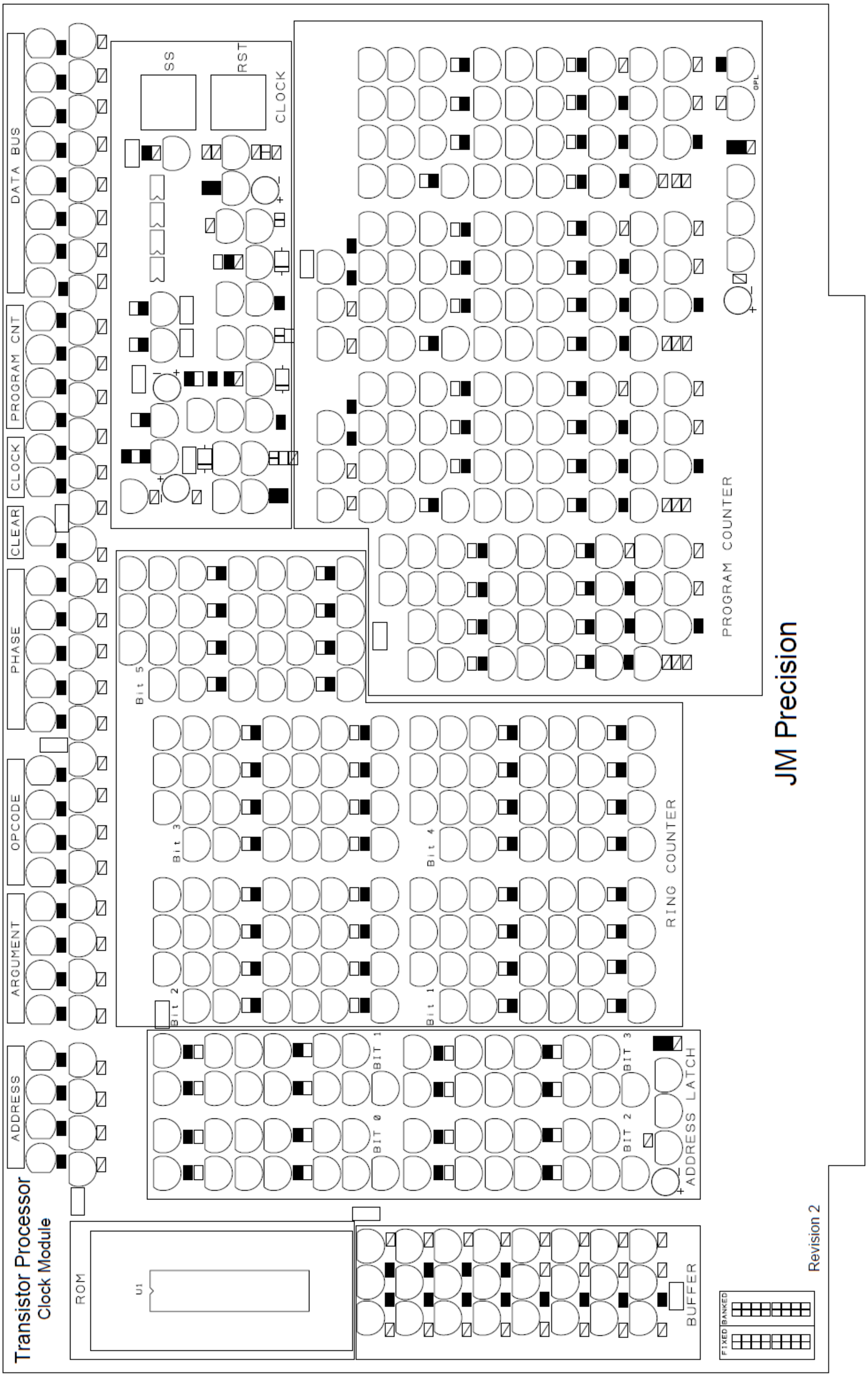
Appendix E – Accumulator Board



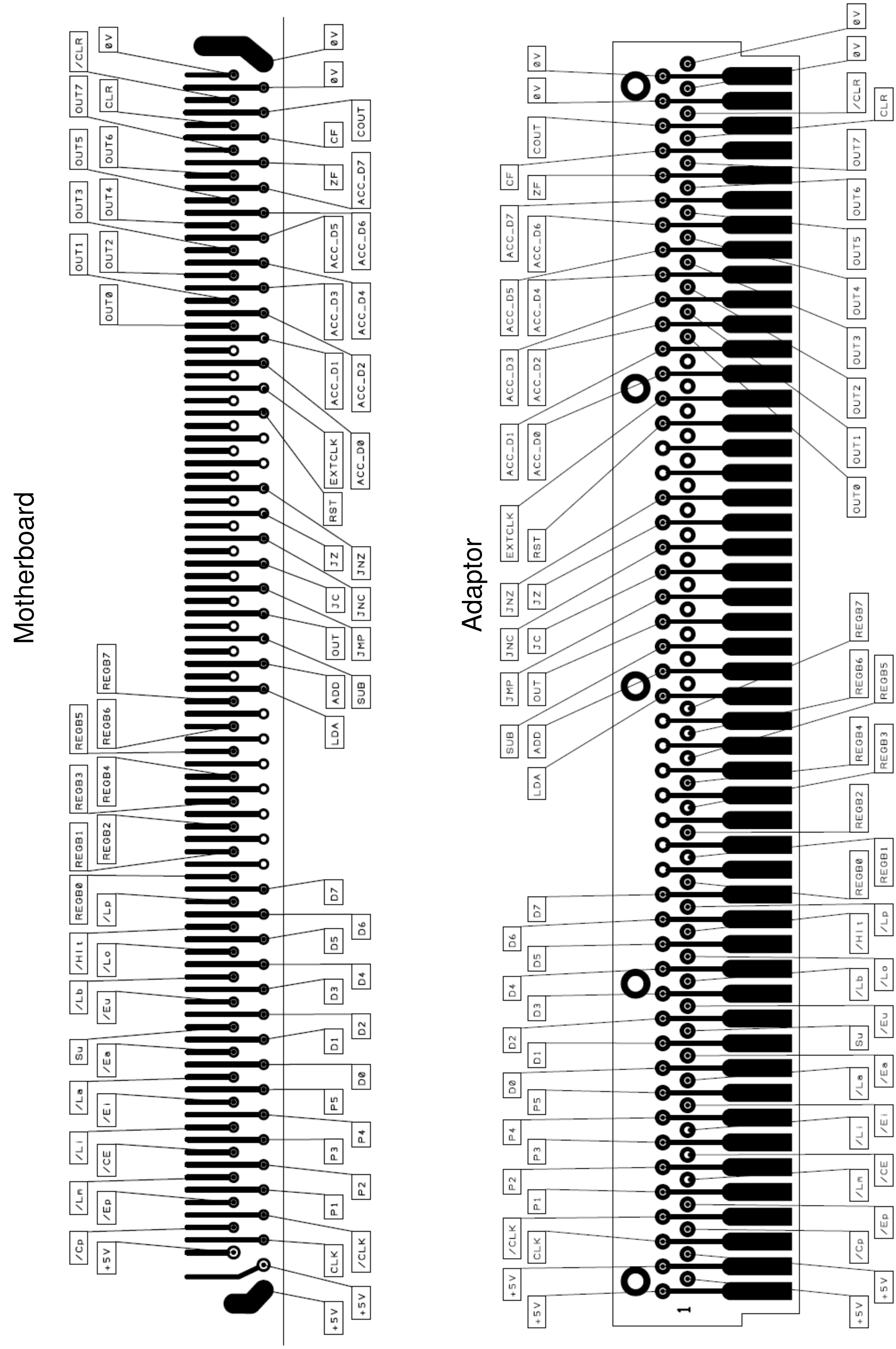
Appendix F – Control Matrix Board



Appendix G – Clock Board



Appendix H – Backplane Connections – Motherboard



Appendix I – Processor Block Diagram